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Prevention of Floods, Stony Brook. 1886

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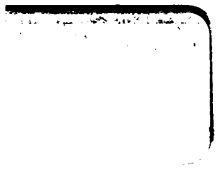

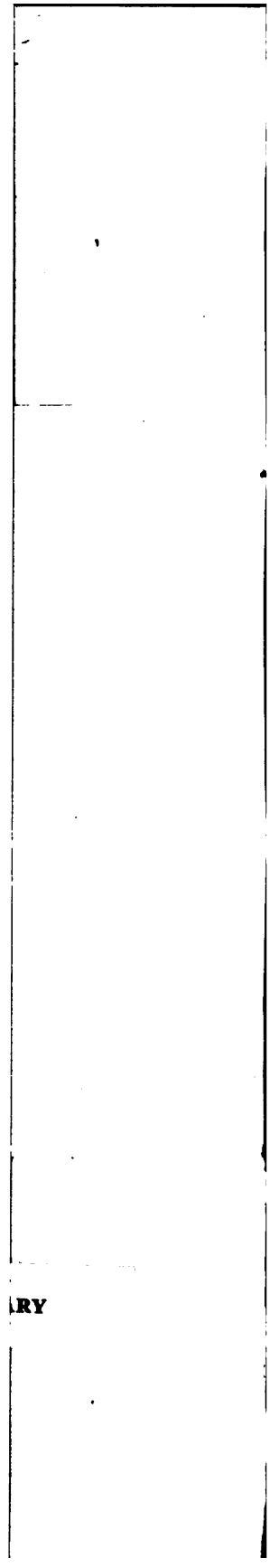
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PREVENTION OF FLOODS

IN THE

VALLEY OF STONY BROOK.

A REPORT BY A COMMISSION

CONSISTING OF

JAMES B. FRANCIS, C. E.,
ELIOT C. CLARKE, C. E.,
CLEMENS HERSCHEL, C. E.

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CITY OF BOSTON.

PREVENTION OF FLOODS IN THE VALLEY OF STONY BROOK.

A REPORT BY A COMMISSION CONSISTING OF JAMES B. FRANCIS, *C.E.*, ELIOT C. CLARKE, *C.E.*, AND CLEMENS HERSCHEL, *C.E.*

To HIS HONOR HUGH O'BRIEN, *Mayor of Boston:* —

SIR, — We were appointed Commissioners by you, in accordance with the following order of the City Council: —

FEBRUARY 15, 1886.

"*Ordered*, That His Honor the Mayor be requested to appoint a commission of three persons, who shall examine the whole subject of the surface-drainage of the section of the city flooded during the late storm, and see if a plan can be devised for preventing such floods in the future; the expense of such commission to be paid from the appropriation for Incidentals."

Having attended to the duties required by the order, we respectfully submit the following report: —

It will facilitate an intelligent comprehension of the problems presented, to state briefly the conditions at present existing, and the way in which such conditions have arisen.

As shown on Plate I. the water-shed of Stony brook extends about seven miles, from within the town of Hyde Park, down to the Back Bay park in Boston, and comprises a total area of about 13.92 square miles. This area can again be divided into several subsidiary parts, tributary to the various branches or to different portions of the main stream. Stony brook is maintained by the rain which falls on this water-shed, and which reaches the stream either promptly through surface affluents, or more slowly through subterranean channels. During the summer droughts the flow diminishes to a fractional part of one cubic foot of water per second; during heavy freshets it may increase to a thousand or more cubic feet per second.

The immediate channels of the main and principal tributary brooks are not, and never have been, large enough to contain the flow during freshets. At such times the brooks overflow their banks, and spread out over adjoining meadow-lands, which are covered from one to several feet deep. These areas of meadow land subject to flooding are indicated on Plate I., and the following table gives an approximate statement of their extent in acres: —

	ACRES.
About the main brook, below Forest Hills . .	38
" " between Forest Hills and Hyde park . . .	133
" " within and above Hyde Park,	166
" Franklin Park branch brook . . .	219
" Roslindale branch brook . . .	109
In Bussey park	25
Total area of meadows subject to flooding .	690

In the original state of the brook and before its surroundings had been modified by human agency, the variations of flow were not so great as at present. The rough condition of the land, covered with trees and bushes, retarded the flow of surface-water, thus lessening the rate at which the water

reached the brook, and more of the rain soaked into the ground, to be contributed slowly to the stream during droughts. In proportion as the surface of the water-shed has been modified, to meet the needs of population, the rate at which water flows into the water-courses has increased, and will continue to increase in the future.

As houses, yards, walks, avenues, and streets multiply, the surface of the ground becomes smoother and more impervious, so that less of the rain soaks into it. The street gutters and drains quickly carry into the brook rain-water which before had been absorbed by the earth or had been so delayed in its passage that water from areas near to the channel had time to flow off before that from more remote regions arrived.

Besides these general causes certain specific changes have been made which have increased the tendency to flooding in the upper portion of the valley, and by storing the water there have diminished the rate at which it reaches the lower part of the brook.

The streets crossing the main valley have been provided with bridges or culverts where they pass over the brook. Sixteen such structures exist between Pynchon street and Hyde Park. Although most of these culverts have been enlarged during the last few years, they were not large enough to let pass the water due to the freshet of last February as fast as it arrived. At that time nearly every street acted as a dam to flood the meadows above it. Cross sections of all of these culverts are shown on Plate III. It will be noticed that the water-ways of many of them have been diminished by putting water or sewer pipes through them. The effect of these structures during the February freshet will be understood by referring to Plate II., which is a profile along the channel of the brook, showing, in blue, the height at which the water stood during the freshet. The obstruction caused by an insufficient culvert is indicated by the difference in height of the water above and below it. The frictional resistance offered by any portion of the channel is indicated by the amount of surface inclination, or by the hydraulic

gradient (shown by a broken line) where the culvert was running full, and under pressure.

The mouth of the brook, originally, was in Roxbury, just below Elmwood street. Here it emptied into tide-water, discharging into a tidal estuary which reached this point from the full basin of Back Bay, by winding through low marsh lands liable to be flooded at high tide.

From time to time, as these marsh lands were artificially raised and built upon, the tidal channel into which the brook emptied was considered a nuisance, and was filled and obliterated. At the same times the brook itself was extended about a mile, by building new covered channels of stone. The shapes and sizes of different sections of this channel are shown on Plate IV., Figs. 50 to 61.

As will be seen, different sections differ considerably in shape, size, and methods of construction; and, as a whole, the channel is very irregular, and not well fitted for the rapid conveyance of water. Its capacity for discharge, with any reasonable head, is about one-tenth of the rate at which water may be contributed to the brook by the whole water-shed. At the times when it was built, however, the small culverts of streets crossing the brook farther up, caused the greater part of the water during freshets to be dammed back upon the meadows, whence it came down no faster than the lower channel was able to deliver it.

A final important change in the condition of the brook was made lately by the city of Boston in straightening, enlarging, and improving the channel for about three miles above the lower covered channel built by Roxbury. Different portions of the improved channel varied considerably in respect to shape and methods of construction. Characteristic sections of it are shown on Plates III. and IV., Figs. 5 to 37.

As a whole the new channel has a capacity for carrying much less water than may be contributed by the water-shed in time of extreme freshet, but very much more than the capacity of the old channel which it replaced, and entirely beyond that of the covered channel below Elmwood street.

This will be readily understood by an inspection and comparison of the different cross sections of the channel, shown on Plates III. and IV. These are selected from a much larger number which we have had measured, and are intended to give an idea of the sizes of all parts of the whole channel of Stony brook, from Hyde Park down to the final outlet through Back Bay park into Charles river. It will be noticed that, as a rule, the upper parts of the channel, which receive least water, are the largest and best fitted for its conveyance, and that the lower portion which must receive the flood from the whole water-shed is small and irregular.

The first considerable freshet which occurred after the improvement of the upper channel came in February of the present year. Rain began to fall at 7.45 A.M. on the 10th, and continued falling till 2.45 P.M. of the 13th. The total precipitation, as deduced from the records taken in the vicinity, was 5.86 inches, to which must be added about two inches for melted snow and ice. The new channel proved entirely inadequate for removing this amount of water, and all of the meadows about the main and tributary streams shown on Plate I. were flooded, in some cases up to six or more feet in depth. A special examination made by us showed that along the line of the main brook within the city limits, and above Tremont street, the water entered 191 dwellings and other buildings; most of them being within the limits of West Roxbury.

Although the new channel was incapable of providing for all of the water, it carried a much larger quantity than before its improvement. Careful estimates, based upon many flood-marks, and the best information obtainable, show that about 500 cubic feet of water a second flowed through the Pynchon-street culverts. This was much more than the covered channel below Elmwood street was able to care for, although the water at its upper end stood several feet above its top, and the total fall through it was about eleven feet at high tide. The water, therefore, rose and overflowed about 63 acres of low territory in the vicinity of and below Elmwood street, flooding yards, buildings, and streets. The

Inspector of Buildings reports that 1,437 buildings in this district, occupied by 3,090 families, were affected.

It may be useful to refer to two erroneous opinions which seem to be held by some persons, and have been alluded to in the daily press. These are: that part of the trouble was caused by the intercepting sewer, and also by the height of water in the ponds of the Back Bay park.

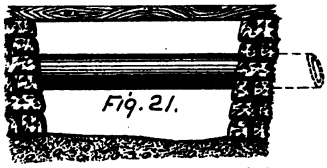
No water whatever was contributed by the intercepting sewer. On the contrary, an indeterminate amount, probably approximating to fifty cubic feet per second, flowed off through that sewer during the storm. After the storm had ceased, when the whole capacity of the Main Drainage pumping-station could be applied to relieving the flooded district, and when some regulating apparatus, which is a part of the system, had been removed, about 150 cubic feet per second were drawn off in that way, and the duration of the flood was thus lessened, as could have been done by no other method.

As already stated, the covered channel was only able to convey a part of the flood, even with an eleven-foot head. Observations made during the flood showed that fluctuations in the elevation of the park pond produced a barely perceptible effect upon the water above. If the surface of the pond could have been maintained at a level with the tide at all stages it would have had little effect upon the height of water in the flooded district.

After these preliminary statements we reach our real object which is to devise a plan to prevent such floods in the future. It is evident that the first step is to determine how much water should be provided for.

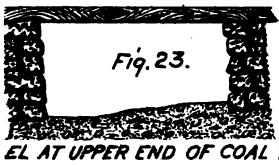
QUANTITY OF WATER TO BE PROVIDED FOR.

The quantity of water to be provided for, at a point in Stony brook, 700 feet above the Tremont-street crossing of the Boston and Providence Railroad, is the maximum flow from a water-shed of 12.727 square miles, due to the precipitation upon it, less the amount evaporated and absorbed

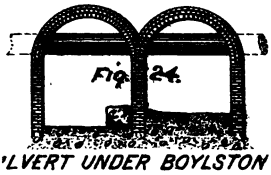


ERT UNDER BOYLSTON AVE.
Area 110.72 Sq. Feet.

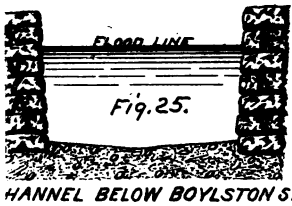
NNEL AT RAILROAD TRESTLE.
Area 111.36 Sq. Feet.



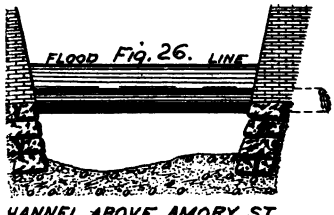
EL AT UPPER END OF COAL YARD.
Area 112.64 Sq. Feet.



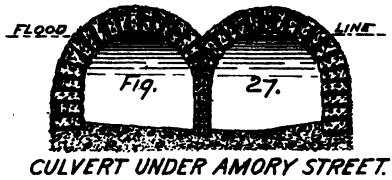
LVERT UNDER BOYLSTON ST.
Area 86.4 Sq. Feet.



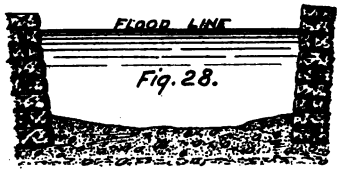
HANNEL BELOW BOYLSTON ST.
Area 130 Sq. Feet.



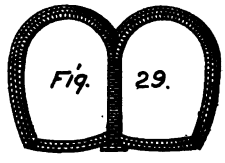
HANNEL ABOVE AMORY ST.
[WHERE SEWER CROSSES.]
Area 105.60 Sq. Feet.



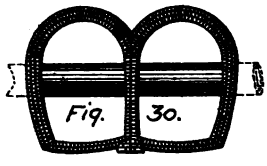
CULVERT UNDER AMORY STREET.
Area 122.2 Sq. Feet.



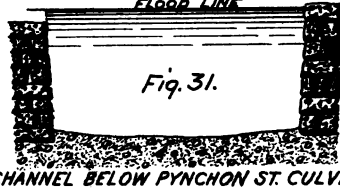
CHANNEL BETWEEN AMORY & CENTRE STS.
Area 162.56 Sq. Feet.



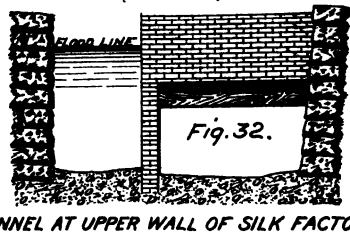
CULVERT UNDER PYNCHON ST.
Area 125.19 Sq. Feet.



CULVERT UNDER PYNCHON ST.
[WHERE SEWER CROSSES.]
Area 88.45 Sq. Feet.



CHANNEL BELOW PYNCHON ST. CULVERT.
Area 215.04 Sq. Feet.



CHANNEL AT UPPER WALL OF SILK FACTORY.
Area 157.0 Sq. Feet.

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by vegetation, or, sinking deep into the ground, discharged at a much later period, in the form of springs, in this or in other water-sheds.

Formulas have been proposed by engineers for computing the maximum flow of streams. Several of them reduced to a uniform notation, with the results as applied to Stony brook, are as follows: —

Q = the maximum flood discharge, in cubic feet per second.
A = the area of the water-shed, 12.727 square miles.
L = the extreme length of the water-shed, 6.0 miles.
B = the average breadth of the water-shed, 2.12 miles.

The Dickens Formula.

$$Q = 825A^{\frac{3}{4}} = 5{,}559 \text{ cub. ft. per sec.}$$

The Dredge Formula.

$$Q = 1{,}300\frac{A}{L^{\frac{2}{3}}} = 5{,}011 \text{ cub. ft. per sec.}$$

The O'Connell Formula.

$$Q = -45.796 + \sqrt{2097.28 + 457.96\ A} = 1{,}886 \text{ cub. ft. per sec.}$$

The Craig Formula.

$$Q = 440 \times B \times N \times \text{hyp. log.}\frac{8L^2}{B}$$

N being an arbitrary constant, varying from 0.37 to 1.95, depending on the meteorological and topographical conditions of the locality, the least value of N is assigned for very flat river basins.

Taking N = a mean of the extreme values = 1.16

Q. = 5,313 cub. ft. per sec.

The Fanning Formula.

$$Q = 200\ A^{\frac{5}{6}} = 1{,}666 \text{ cub. ft. per sec.}$$

The Bürkli-Ziegler Formula.

$$Q = C\,R\sqrt[4]{\frac{S}{A}}$$

In which

Q = The maximum flood discharge, in cubic feet per second per acre.

C = A coefficient, ranging from 0.31 to 0.75, depending on the nature of the surface, the higher coefficient being for paved streets and roofs, the lower for rural sections of suburbs. Average recommended, 0.62.

R = Average intensity of rain during the period of heaviest fall in cubic feet per second per acre. Assumed for the whole area of the water-shed of Stony brook for 0.5 inch of rain per hour, equivalent to 0.504 cubic feet per second per acre.

S = General grade of area per thousand, assumed for Stony brook water-shed at 20.

A = Area of water-shed in acres; for Stony brook, 8,145 acres.

$$Q = 0.06956 \text{ cub. ft. per sec. per acre.}$$

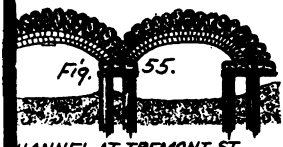
Or, for the 8,145 acres of water-shed of Stony brook, 567 cub. ft. per sec.

The Fanning formula is deduced from some American observations, few in number, and is intended to represent their average result.

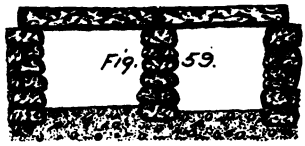
The Bürkli-Ziegler formula is from experience in Europe, and appears to be deduced from much smaller water-sheds than that of Stony brook.

The other formulas appear to be deduced from observations at various localities in India, in which the areas of the water-sheds are very large, and in most of which the rainfall at certain seasons far exceeds the amount here.

The results of the several formulas are very discordant, as, indeed, is to be expected, coming as they do from localities differing widely in the essential characteristics on which the results depend. In our own neighborhood, except by accident, no two water-sheds would give the same maximum flood discharge from the same area; and even the same water-shed, under different conditions as to season, amount of frost and snow, previous saturation, etc., might yield flood-discharges, with rainfalls of similar duration and intensity, twice as great in one case as in the other.



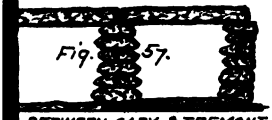
HANNEL AT TREMONT ST.
Area 64.96 Sq. Feet.



CHANNEL AT B. & P. R. R.
Area 100.92 Sq. Feet.

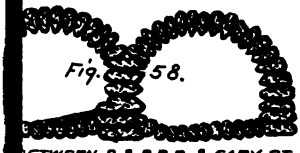
AT NORTHERLY SIDE OF TREMONT ST.
Area 78.08 Sq. Feet.

CHANNEL BETWEEN HUNTINGTON AVE. & B. & P. R. R.
Area 120.64 Sq. Feet.

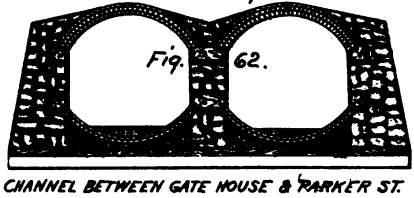


BETWEEN CARY & TREMONT STS.
Area 88.32 Sq. Feet.

CHANNEL NEAR HUNTINGTON AVENUE.
Area 136.30 Sq. Feet.



ETWEEN B. & P. R. R. & CARY ST.
Area 118.40 Sq. Feet.



CHANNEL BETWEEN GATE HOUSE & PARKER ST.
Area 160. Sq. Feet.

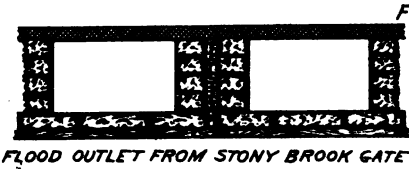


Fig. 63.

CHANNEL OF STONY BROOK FOR ORDINARY FLOW.

FLOOD OUTLET FROM STONY BROOK GATE-HOUSE INTO POND OF BACK BAY PARK.

Total Area of Outlet & Channel. 158.48 Sq. Feet.

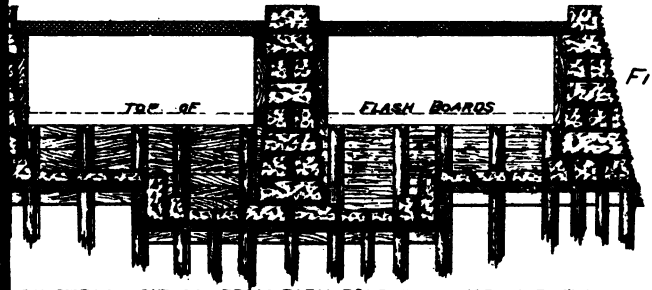


Fig. 64.

CHANNEL OF STONY BROOK. FOR ORDINARY FLOW.

CON STREET OUTLET FROM PARK POND INTO CHARLES RIVER.

Total Area of Outlet & Channel 321.07 Sq. Feet.

It being obvious that we could not rely on the recorded formulas as a means of estimating the maximum flood discharge to be provided for, we have endeavored to arrive at it by a special study of the valley of Stony brook and of the circumstances attending the flood of February last, together with such other data as we could obtain bearing on the case.

The following table gives the amount of rainfall reported at stations within a few miles of the Stony-brook valley during the storm between 10th and 14th of February, 1886: —

LOCALITY.	Rainfall, Inches.
Boston U.S. Signal Service	5.62
Boston Water-Works pipe-yard, Albany street	5.76
Chestnut Hill Reservoir, Boston Water-Works	6.09
Harvard College Observatory	5.70
Blue Hill Observatory	6.13
Average of rainfall at above places	5.86
Milton	5.60
Waltham	6.08
Medford	5.58
Melrose	5.60
Lynn	5.68
Mystic Pumping Station, Boston Water-Works	5.11
Mystic Lake	5.64
Lake Cochituate	4.95
Framingham Centre	4.64
Westboro'	4.63

The greater portion of the rain fell on the 11th and 12th, during an interval of twenty-four hours, and is indicated in the following table, quoted from the paper of Prof. Winslow Upton, of Providence, on the distribution of rainfall in New England during this storm: —

STATIONS.	Time of Beginning.	Time of Ending.	Total Rainfall.	Interval of 24 hours during heaviest rainfall.	Rainfall in 24 hours.
New York .	10th, 10 30 A.M.	13th, Noon.	3.41	11th, 11.00 A.M.; 12th, 11.00 A.M.	2.99
New London,	11th, 6.00 A.M.	13th, 4.20 P.M.	8.93	11th, 11.00 P.M.; 12th, 11.00 P.M.	6.66
Providence .	11th, 1.00 A.M.	13th, 11.30 P.M.	8.13	12th, 7.00 A.M.; 13th, 7.00 A.M.	5.65
Boston . . .	11th, 7.45 A.M.	13th, 2.45 P.M.	5.62	11th, 11.00 P.M.; 12th, 11.00 P.M.	4.45
Newburyport	10th, 5.30 P.M.	13th, 10.30 P.M.	4.78	11th, 9.00 P.M.; 12th, 9.00 P.M.	3.30

In addition to the rainfall there were snow and ice on the ground, the amount of which cannot be exactly determined. Prof. Upton says, "Several persons have independently estimated that the equivalent of two inches of water was obtained from the snow and ice. This estimate is not excessive, and may be adopted for the region where the rainfall was greatest."

Information derived from a variety of sources shows that it was about the same on the Stony-brook water-shed; but some of it had, no doubt, disappeared before the commencement of the twenty-four hours of greatest rainfall. The remaining snow must have acted as a sponge and retained a portion of the previous rainfall, to flow off with that which fell during the twenty-four hours, during which time the ice and snow all disappeared, and probably the rain, together with the melted snow and ice, for the twenty-four hours, was tully six inches. There had been heavy rain immediately previous to this twenty-four hours, which must have partially filled the streams, and the ground being either frozen or where not frozen, thoroughly saturated, the circumstances were favorable for a large part of the water flowing off the ground immediately into the water-courses, or accumulating in low places. We estimate that about three-quarters of it flowed off the ground on which it fell in twenty-four hours, which for the entire water-shed of 12.727 square miles is equivalent to a flow of 1,540 cubic feet per second; but only a portion of this quantity reached the lower end of the brook in twenty-four hours, the greater part being held back in the

meadows in consequence of the small size of the street culverts, and the channel of the brook.

There is, however, a liability to a much greater rainfall.

Professor Upton, in the paper above referred to, reports that in parts of Rhode Island and Connecticut, on an area of 750 square miles, or about sixty times that of the Stony-brook water-shed, over eight inches of rain fell in the storm of February 10 to 14, last, to which should be added the snow and ice previously on the ground, which he reports as equal to two inches of water, making a total, equivalent to over ten inches of rainfall in the whole storm. Of this, eight inches may be taken as the maximum amount in twenty-four hours. A similar rainfall on the Stony-brook water-shed would cause a flow off the ground of about 2,050 cubic feet per second.

In the storm of October 3 and 4, 1869, it is on record that from 9 to 12.35 inches of rain fell in the vicinity of Hartford, Conn., on an area of 1,046 square miles, in about thirty hours, or an average of about 218 cubic feet per second per square mile; a similar rainfall on the water-shed of Stony-brook would amount to 2,774 cubic feet per second.

The greatest rainfall in this vicinity, of which we find any record, was at Waltham, in a shower on the afternoon of August 21, 1860, when the Boston Manufacturing Company's record shows a fall of 5.63 inches in three hours, or at the rate of 1,211 cubic feet per second per square mile. A similar rainfall, on the entire area of the Stony-brook water-shed, would amount to 15,412 cubic feet per second. This great rainfall was undoubtedly confined to a comparatively small area. By reference to other rain-gauge records, kept in this part of the State, we find the total rainfall of the same day to have been as follows: —

At Lowell	0.56 inches
At Lake Cochituate, for the whole week, including August 21	0.96 inches
At Boston, by J. P. Hall's record, for August 21 and 22	0.90 inches

At Harvard College Observatory 1.938 inches is recorded, with the following memoranda: "21st. Continued and heavy thunder, with abundant rain, began at 10 A. M. 22d. Accounts from Waltham give intelligence of a most violent storm in that neighborhood yesterday; the quantity of rain which fell was six inches; in several places the roads were so washed away as to be impassable, and the crops flooded with water. In Boston, Roxbury, Dorchester, etc., the quantity of rain was not unusually large."

We are of opinion, however, that while the probability of a rainfall of such intensity and duration as the Waltham shower, extending over the whole or any large portion of the Stony-brook water-shed, is too remote to warrant the great expense that would have to be incurred to fully provide for it, it is not unreasonable to expect that it may occur with equal severity on an area of one or two square miles, with a less amount on adjoining areas; and if this should be on a part of the water-shed closely built over, the effect of which is to cause the rainfall to flow off rapidly into the stream, a maximum flow of two or three thousand cubic feet per second would result.

It might be thought that the greatest flood would be caused by a heavy, warm rain falling on frozen ground covered with snow; but the greatest flood in the Merrimack river, of which there is any knowledge, certainly for more than one hundred and fifty years, was in the month of October, and was caused by a continuous, southerly, heavy rain of about forty-eight hours' duration.

On a mature consideration of all the conditions that occur to us, but without undertaking to provide for remote possibilities, we are of opinion that a rainfall of twelve inches in twenty-four hours, or its equivalent in rain, melted snow and ice should be provided for. The proportion of this that would flow off in the stream during the same time depends largely upon the condition of the valley. In its present condition probably not more than one-quarter of the whole amount would reach the lower end of the valley; the larger part of the remainder would be held back in the meadows, and other

low places to flow off gradually, as in the flood of February last. Improvements will, no doubt, be made at an early day to prevent this; and, of course a proportionally larger quantity will flow off in a given time. As the land becomes occupied by buildings, and assumes an urban character, with houses close together and with paved streets, or even if the surface is merely laid out as a park, with drive-ways and subsoil drains, a still larger proportion will flow off in a given time, until, ultimately, if the city continues to grow in that direction as it has done, we estimate that, in a rainfall such as we are considering, the maximum flow in the stream would be about three-fourths of the rainfall during the same length of time.

The flow in the stream would not be synchronous with the rainfall, but later; and, as the storm progressed, the tendency would be for the rate of flow to approach the rate of the rainfall, and, if the rain continued to fall indefinitely at a uniform rate, the flow in the stream and rainfall would, after a certain interval, be nearly the same.

Twelve inches' rainfall in twenty-four hours on the watershed of Stony brook is at the rate of 4,107 cubic feet per second. In the present condition of the stream above the Pynchon-street culvert, we are of opinion that the maximum flood at that point would correspond to about one-fourth of that rate, or say 1,000 cubic feet per second; and when the channels of Stony brook and its tributaries above the culvert are improved to an extent to relieve the meadows from being flooded, we estimate that the maximum flow in the stream would be at about one-half the rate of the rainfall, or say 2,000 cubic feet per second, and ultimately, when the valley is all closely built upon, the rate of flow would be equal to three-fourths of the rainfall, or about 3,000 cubic feet per second.

PROVISION FOR FLOOD DISCHARGE.

We assume that the channels of the main stream and tributaries above Tremont street will be improved, from time to time, in order to do away with the flooding of low lands

in West Roxbury, so that in providing at present for the water below that point, it will be expedient to provide for the quantity which will flow there after that improvement has been completed. On the other hand, we do not think it necessary to provide at present for the quantity that may flow in the distant future, when the whole water-shed shall be solidly built up; but only to point out a method by which further relief can then be obtained should it prove necessary.

We therefore have, as data upon which to devise our present methods of relief, 2,000 cubic feet of water a second to be disposed of at the lower end of the water-shed near Tremont street, and a gradually diminishing quantity as we ascend the brook, amounting at the confluence of the Franklin-park branch brook and the main stream, to about 900 cubic feet a second.

How can this amount of water be disposed of? It is evident that there are but two ways in which it can be done.

1. By providing one or more channels of sufficient capacity to convey to the sea all of the water as quickly as it arrives.

2. By providing one or more storage-basins, in which flood-water during storms can be stored, and be let off gradually through the present or other small channels.

The second of these methods will be first considered.

As has been before stated, about 700 acres of low land were flooded, and served as storage-basins, during the February freshet. The average depth of water in these basins is estimated to have been about four feet. The water was retained in them by the city streets, which acted as dams. Notwithstanding this large amount of storage, more water flowed down upon the city than could be carried off by the present channel. It is obvious, therefore, that to obtain relief by this method from similar freshets (and even greater ones may be anticipated), it would be necessary either to provide basins of larger area or to make the water in them stand much higher. The height at which the water stood in February was sufficient to cause damage by flooding many streets and buildings, and it could not stand higher without

causing more damage. It would hardly be possible to find much larger areas, aggregating say 1,000 acres, where shallow basins, that would not cause great damage, could be constructed. A large number of dams, with their gates and other appurtenances would be needed, and it would be difficult to ensure that they should be in efficient working condition on the rare occasions when they would be required. Moreover, the only available places for storage are in the upper portions of the water-shed, above Forest Hills, and so much water would be contributed to the brook below that point that the building of such basins would not obviate the necessity and expense of enlarging the channels in the lower part of the valley. In any case, the cost of securing the land, removing buildings, raising streets, building dams, etc., would entail an expense which would reach several million dollars, or much more than would be needed to obtain relief by other methods.

There remains to consider the only alternative method,— that of providing one or more channels by which the water can be removed to the sea as fast as it arrives.

Shall there be a single channel or shall there be more than one?

It is evident that the only outlet for the lower portion of the water-shed is in the direction of natural flowage into Charles river. The upper portion of the water-shed, however, is nearer to Neponset river, although separated from it by an elevated dividing ridge. It was thought that the feasibility of diverting water from this portion into the Neponset was worth considering. Surveys to this end were accordingly made. The elevations were determined of all parts of Stony brook and of the neighboring parts of Neponset river at its ordinary stage, and also during freshets.

The farthest point up Neponset river at which the elevation of flood water is lower than that of Stony brook, where it would be desirable to divert it, is below the Central-avenue dam at Milton Lower Mills. The elevation of the water at this point during the February freshet, was 24.61 feet above Boston city base, or approximate mean low-water of the sea.

The elevation of Stony brook at the confluence of the main stream and the Franklin-park branch is 33.2 above the same datum. Between the two points, therefore, is a fall of about nine feet. The distance between them is about 13,400 feet. This would give a fall of about one foot in 1,500, which would afford sufficient inclination for a conduit to divert the brook water to the river. The total area of that portion of the water-shed which feeds the brook at this point is 3,552 acres, and on our assumption of the quantity of flood-water to be provided for, as soon as the brook channels are so improved as to prevent flooding, this area would furnish 895 cubic feet of water a second during extreme freshets. In the distant future, when (if ever) the area was solidly built upon, the quantity would be 1,342 cubic feet. Building a conduit to divert the former quantity to Neponset river would lessen by so much, the quantity at present to be provided for below, reducing it to about 1,100 cubic feet a second.

This would be a great advantage, and surveys and estimates were made to ascertain how much it would cost to secure it. The most favorable location for any such conduit is indicated on Plate I. Starting at the junction of the Franklin-park branch with the main stream, the line first follows the low land bordering the former brook up to Walk Hill street, a distance of about 2,200 feet. Thence the line follows Walk Hill street to Back street, and thence continues on a nearly direct line across private property to Neponset river, just east of Central avenue. For nearly the whole distance after reaching Walk Hill street, or about 11,000 feet, the surface of the ground is forty or more feet above the level of the proposed conduit, and it would be necessary to build the latter by tunnelling. Its internal diameter, if lined with brickwork, would be about 13 feet, and if unlined where it passed through solid rock, about 16 or 17 feet.

It was not considered necessary to ascertain the character of the ground to be penetrated more exactly than could be done from surface indications. Evidently a portion of the tunnelling would be through rock, and other portions through

gravel and soft ground where much water would be met with. Even supposing that the conditions affecting the work should turn out more favorable than could be anticipated, approximative estimates showed that the cost of the work could not be assumed to be less than $1,000,000, and might exceed that sum.

As the channels below, in Roxbury, are too small to care for the 1,100 cubic feet a second, which might still flow down to them, the building of a conduit to Neponset river would not do away with the necessity of providing a new channel in the lower portion of the water-shed. Its only advantage would be in lessening the extent of new channel which would be required below, and permitting a smaller channel of 1,100 cubic feet capacity to be built in Roxbury, instead of one of 2,000 feet capacity. The saving in cost, however, would be very much less than the $1,000,000 or more required for the Neponset conduit.

Although we do not deem it advisable at present to divert water from Stony brook to Neponset river, the feasibility of the scheme is of considerable value. It permits adopting measures for present relief without reference to possible remote future contingencies; since, should such contingencies ever arise, this method for further relief will always be available.

Having thus eliminated all other remedial arrangements, it remains to devise a channel of sufficient capacity to convey safely to Charles river the flood-water of the whole water-shed. The wording of the order under which we act requires us to devise a plan which will do away with liability to flooding throughout the whole extent of Stony brook within the city. As, however, far the most damage was from flooding in Roxbury, and the most urgent need is for protection from a similar catastrophe in that region, we think it probable that remedial measures to that end may be desired first, and the protection of the upper valley may be left to be accomplished somewhat later. Accordingly we shall divide our consideration of plans into two parts: —

1. A plan for preventing flooding in Roxbury below the Tremont-street crossing.

2. An extension of the foregoing plan, to prevent flooding above the Tremont-street crossing, chiefly in West Roxbury.

In its present state above Tremont street, Stony brook, in time of freshet, may yield 1,000 cubic feet of water per second. As the channel and street-culverts above are enlarged this amount may increase to 2,000 cubic feet a second. If a new channel of 1,000 cubic feet capacity were provided it would answer present emergencies, but would soon prove inadequate. In the interest of true economy it is necessary to build a channel large enough for future needs, that is, one capable of safely discharging 2,000 cubic feet of water each second.

Several interdependent elements enter into the proper designing of such a channel: —

1. Its inclination, or, more strictly, its hydraulic gradient.

2. Its size and shape.

3. Its mode of construction and the quality of its interior surface.

4. Its location and the character of the ground in which it is situated.

The size of channel required to discharge any given quantity of water is chiefly governed by the inclination which can be secured. The inclination is determined by the comparative elevation of the surface of the water at the upper and lower ends, respectively, of the conduit. In this case the elevation at the lower end of the conduit will be that of the water in Charles river, or of the pond in the Back Bay park, connecting with Charles river. The river being a tidal stream, its elevation is constantly varying, and to be safe its elevation at high tide must be taken. The rise of the tide itself varies considerably. The average rise is about 10.44 feet above Boston city base. In April, 1851, what is known as the Minot's ledge tide rose to 15.66 feet above city base. The chance of an extreme freshet on Stony brook water-shed occurring at precisely the same time as

such an unusual tide is so slight that it would be an unreasonable precaution to assume 15.66 as the elevation of the water in the river.

The following table, compiled from data furnished by the United States Coast Survey, shows the number of tides which have risen above the elevations given, during a period of eighteen years: —

Number of tides above			13.14	feet above	Boston City base		. .	41
"	"	"	13.50	"	"	"	. .	19
"	"	"	14.	"	"	"	. .	8
"	"	"	14.50	"	"	"	. .	3
"	"	"	15.	"	"	"	. .	1
"	"	"	15.50	"	"	"	. .	1

Less than 13 feet high the number increases very greatly. Considering the chances, we think it reasonable to design the works required, on the assumption that the tide in Charles river will not be higher than Grade 13 during the occurrence of an extreme freshet.

In deciding where to place the outlet of the new channel, we first notice that Charles river is nearly twice as far from the upper end of the proposed new structure as is the pond in Back Bay park. It would be impracticable to build any new channel within or parallel to the park which would have as great capacity and require as little inclination as will that already furnished by the park pond. The available fall to the park pond would be five feet and to the Charles river would be but one foot more, or six feet. Consequently, a channel to reach Charles river, having less inclination, must be considerably larger, and, being nearly twice as long, would be more than twice as costly as one ending at the park pond.

About one foot fall must be allowed for the inclination of the water in flowing from the outlet through the pond to the river. This will make the height of the water at the channel outlet, at high tide, 14 feet above city base, and we assume this elevation as that of the water at the lower end of the channel.

It might be thought that the water in the pond might be kept at a lower elevation than that of the river, and that the pond might be used as a storage reservoir to receive the water of Stony brook during freshets. Calculations based upon the area of the pond and the quantity of water which may flow during great freshets, after improvements have been made, show that the surface of the pond would rise faster than the tide, and that nothing could be gained in that way.

Various practical considerations require that the upper end of that portion of the new channel first needed to prevent flooding in Roxbury, should begin (as shown on Plate I.) at the present channel at a point alongside of the Boston and Providence Railroad, about 700 feet above the Tremont street crossing of the railroad. For reasons which we shall explain further on it will be best that the surface of the water at this point should not be permitted to rise higher than Grade 19. We have, therefore, an available fall of 5 feet between the upper and lower ends of the new channel. The length of the new channel, by the most available line which we have been able to select, is about 4,542 feet, and the water flowing through it can have an hydraulic inclination of about one foot in 900. To discharge 2,000 cubic feet of water a second, a well-built brick conduit with an hydraulic inclination of one in 900 must be nearly 17 feet in diameter.

We think it will be easier, cheaper, and more satisfactory to build an entirely new conduit, capable of conveying the whole flood from the water-shed above Tremont street, than it would be to attempt to enlarge sufficiently the present channels below that point. When the water at their upper end does not rise so high as to flood the Boston Belting Co. the present covered channels, at high tide, cannot discharge more than 200 cubic feet a second, or no more than may still reach them from city areas, which must always be tributary to them. To enlarge them so that they could accommodate 2,000 cubic feet more, would imply entirely rebuilding them at a cost very much greater than that of a

separate conduit. Elevations taken at the Boston Belting Co.'s yard, on the line of the brook, a little below Tremont street, show that the water cannot rise above Grade 15 without beginning to flood basements and cause damage. As it may stand at Grade 14, at the outlet in Back Bay park, but one foot fall would be available by this route as against five feet by the route selected, which is somewhat shorter. This lack of sufficient fall would require a channel on the old location to be twice as large as the one we propose. It would be too large for the streets in which are the present channels, and would require encroaching on the houses on either side. It would be built under the disadvantage of being obliged to maintain the flow of the brook through or around the new work. From the upper end of the proposed improvement to the outlet in Back Bay pond, the length of the new channel will be 4,542 feet; while the length of the old channel, below the same point, is 6,400 feet. Thus by adopting the new route a large saving in distance is effected.

It has been suggested that the brick conduit, in Tremont street and Linden park, which supplements a part of the old channel, might advantageously be extended down Tremont street to reach the lower half of the covered stone channels, where they are a little larger than above. Doubtless a little more water could be removed in that way than as at present, but the quantity would be so small in proportion to the capacity needed, that the occurrence of floods would not be obviated.

A number of routes for the proposed new channel were examined. That finally selected is shown on Plate I., where is also given a longitudinal section indicating the elevation of the conduit relative to the earth surface and the geological character of the ground through which it will pass. The upper end of the conduit is located about 700 feet above the Tremont-street crossing of the Boston & Providence Railroad. The connection between the old and new channels should be so made that a moderate quantity of water, equal to that flowing in the brook at its ordinary stage, and sufficient for the use of the Boston Belting Company, shall always flow down by the old

way. Water is to overflow into the new channel only when its quantity is in excess of what the old channel can dispose of without doing damage. At this point provision should be made for intercepting and removing floating substances, gravel, and miscellaneous rubbish brought down by the brook.

The general shape of the upper portion of the proposed new conduit is shown on Plate V., Fig. 1. The mode of construction will, of course, be varied to meet the requirements of the different kinds of ground in which it will be situated. The line first crosses the tracks of the Boston & Providence Railroad, and follows the westerly side of the railroad location to Tremont street. For most of this distance the conduit will be surrounded by solid rock, and the side-walls can be omitted, the trench being blasted out just wide enough to permit putting in smooth brick side-linings at the required dimensions. Crossing Tremont street and continuing in solid ledge rock, the conduit is to be built on a nearly direct line across private land to the head of Halleck street. Passing down Halleck street, where side-walls will be required, the conduit turns by an easy curve into Prentiss street, which it follows to its junction with Parker street. Just before reaching the latter point the street surface falls, so that the arch of the single conduit would come too near to the top of the ground. The structure cannot be lowered sufficiently to avoid this without interfering too much with the proposed main drainage sewer which must eventually be built in Huntington avenue, to reach Longwood and Brighton.

Just before entering Parker street it will, therefore, be necessary to change the shape of the conduit and to substitute for it the double structure shown on Plate V., Fig. 2. This will require a greater width of excavation, and will be somewhat more expensive to build. Continuing down Parker street, a point is reached where, for a distance of about 550 feet, deep beds of mud will be encountered, and a foundation on piles will be necessary. Crossing Huntington avenue the conduit is located in Huntington entrance of Back Bay

PLATE V.

STONY BROOK COMMISSION.

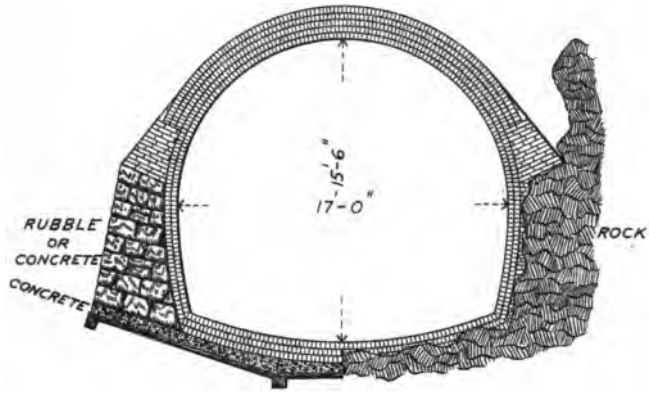
Sections of proposed Channel of Stony Brook to prevent flooding in Roxbury.

JULY, 1886.

SCALE OF FEET.

5 0 5 10 15

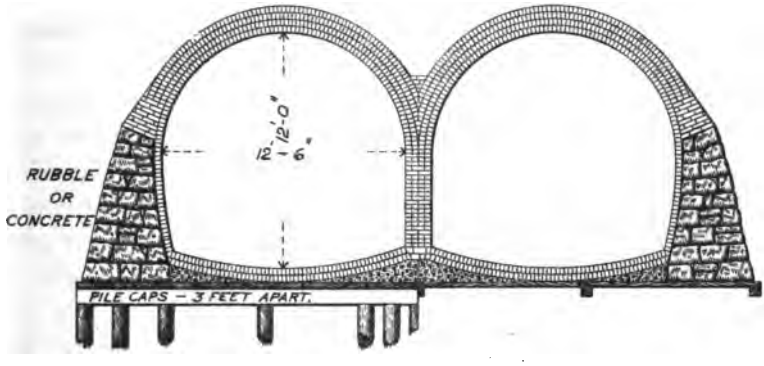
FIG. 1.



HALF SECTION IN EARTH.

HALF SECTION IN ROCK.

FIG. 2.



HALF SECTION ON PILES.

HALF SECTION IN SOLID EARTH.

HELIOTYPE PRINTING CO BOSTON.

park, and its outlet is to be on the border of the park pond. Gates or stop-planks must be provided at this point so that the pond water can be kept out of the conduit when it is to be cleaned. Side entrances, or large man-holes, should be built near the lower end of the conduit by which it can be entered and through which gravel and other accumulations can be removed.

To intercept the sewage furnished by the Parker-street common sewer, which otherwise would enter the pond of the Back-Bay park, and to furnish a means of emptying the water from the proposed new conduit whenever it is necessary to remove accumulations of gravel and other materials therefrom, it will be advisable to extend a branch of the main-drainage system from the corner of Huntington avenue and Camden street to and under the new conduit. Building this sewer as far as and under the present channel of Stony brook is already under consideration by the City Council, at an estimated cost of $33,000. The additional length we estimate to cost $14,000. As it is probable that the whole of this extension will soon be built, in any event, we have not included its cost in the estimate for the new conduit, but have given it separately.

In Parker and Prentiss streets it will be necessary to remodel the systems of sewer, water, and gas pipes. Independent sets of such pipes will be needed on each side of the street, since the top of the new conduit will be too near the surface of the street to allow service-pipes and house-drains to pass over it. In Station and Tremont streets the conduit will be so low that no essential changes in existing arrangements will be required.

By building the above-described conduit the danger of flooding to that part of the city below where it begins will be done away with. Having regard to present and future needs, and to true economy and efficiency, it is our opinion that this is the best method of accomplishing the desired end.

We are of opinion that it would be *possible* to build this conduit in one working season, provided the rock excava-

tion were done during the previous winter, and the whole work were prosecuted under the most skilful management and with the utmost energy.

We submit below an estimate of the cost of completing this section of work. The estimate is based on present market rates for materials and labor, and is believed to be ample, provided the work is superintended with reasonable fidelity and intelligence: —

4,542 lineal feet of conduit, including works at inlet and outlet	$408,872 00
Remodelling of systems of water-pipes and common sewers	15,823 00
Contingencies (say) 10 per cent. . . .	42,469 00
	$467,164 00
Engineering and Superintendence, 10 per cent.,	46,716 00
Total cost of construction	$513,880 00
Land damages	80,000 00
Total cost of improvement	$593,880 00
Cost of extending main-drainage sewer in Huntington avenue	$47,000 00

We next pass to the second part of the problem, which is, to devise a remedy for the flooding of land bordering the brook in West Roxbury, and in Roxbury above Pynchon street. It is easy to find a remedy, but not a cheap one. It consists in providing a channel of sufficient capacity to carry off the water as fast as it comes, without letting it rise high enough to do damage. The only difficulty lies in deciding what form of channel, location, and mode of construction will prove most economical and most efficient.

The following table gives the areas of the water-shed above certain points on Stony brook, and shows the quantity of water which would flow past these points if the water-shed

furnished six inches of water in twenty-four hours at a uniform rate.

AREAS.		Acres.	Sq. miles.	Cubic feet per second.
At junction with Franklin-Park branch	excluding branch	1,719	2.685	433
	including "	3,552	5.549	895
At junction with Roslindale branch	excluding "	3,762	5.877	948
	including "	5,034	7.864	1,268
At junction with Bussey-Park branch	excluding "	5,212	8.142	1,313
	including "	6,165	9.631	1,554
Above Washington st., near Williams st.		7,177	11.213	1,809
" head of Pynchon-st. culvert		7,928	12.387	1,998
" head of proposed lower channel		8,145	12.727	2,053
" Back Bay Park		8,909	13,920	2,245

The districts about Stony brook most subject to flooding are in West Roxbury above Williams street. From Williams street down, therefore, the channel must be such as will drain these districts, and estimates show that the cheapest structure which can be built to do this will be placed somewhat lower than is necessary to prevent flooding in the territory through which it passes. Its depth, however, is of great advantage, in that it allows water-pipes and sewers to pass over it without interference.

The broken red line on Plate II. shows the hydraulic gradient or maximum flood-line finally determined upon. On the same plate is shown in black, the bed of the brook, the height of its side-walls or of the surface of the meadows, where there are no side-walls, and the positions of the different pipes crossing it.

The new channel may be open like the present one (but of greater capacity), or it may be a covered conduit. In either case its bottom must be considerably lower than that of the present channel. As will be seen from the profile, the bottom of the present channel is but three or four feet below the adopted maximum flood line, and a new channel of suffi-

cient capacity, when flowing only three or four feet deep, would be wider than it would be practicable to build through the territory where it must be situated.

On Plate VI. are shown sections of the present channel, and of open and covered ones, respectively, of sufficient capacity to convey safely the flood-water which may flow in the brook below where the Bussey-park branch enters it at Forest Hills. Above that point less and still less water would be received, and a corresponding diminution could be made in the size of channel. As the interior surface of the open channel is considerably rougher than that of the other, the former requires a somewhat larger cross-sectional area. Omitting land damages, and with the depth of excavation indicated, we estimate the average cost per lineal foot of the two channels shown on the plate to be $80.00 for the open one, and $79.00 for the covered conduit.

The slight excess in cost of the open channel over the covered one would be increased in several ways. Land damages would be larger in the case of the former, on account of its greater width, which would cause it to encroach more frequently upon adjacent buildings, and also because the original surface would not be restored for use as it would be over the covered conduit. The wider open channel would entail the necessity and expense of street bridges, and of somewhat difficult crossings for water, gas and sewer pipes. It also would be somewhat less permanent in character, being exposed to the action of frost, and would cost more for maintenance.

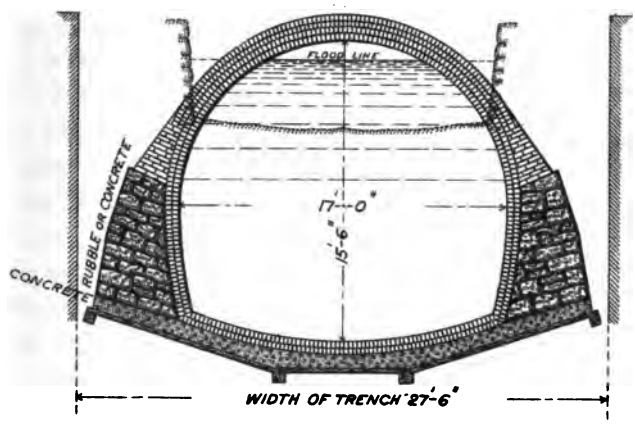
Moreover, it would be almost impossible to prevent an open channel from being used as a place in which to dump refuse. The present channel is thus abused. Members of this commission, who have waded through it, found it encumbered nearly throughout its whole extent with stones and gravel, old iron and tin-ware, boots and shoes, boards, cart-wheels, dead animals, clothing, and all kinds of miscellaneous rubbish. Accumulations of such matters in a channel interfere very seriously with its capacity for discharging water.

STONY BROOK COMMISSION.

Comparison between Open and Covered Channels of the same capacity, showing also the relative location and size of the present channel between Boylston Avenue and Green Street.

JULY, 1886.

FIG. 1.



SCALE OF FEET.

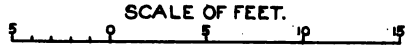
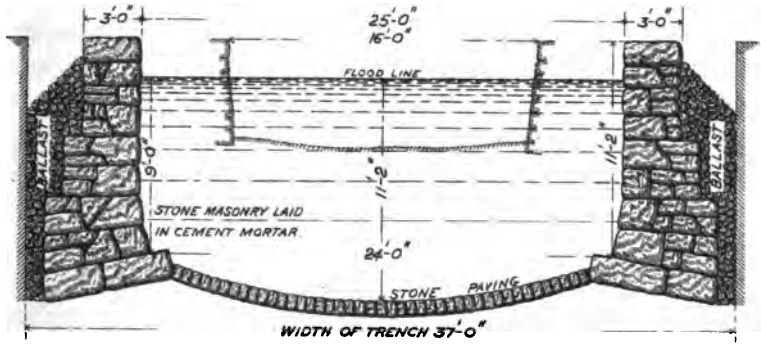


FIG. 2.



HELIOTYPE PRINTING CO. BOSTON.

These considerations lead us to advise that, in extending a new channel up the valley, it be built as a covered conduit as far as the junction of the Bussey-park branch above Forest Hills station. Above that point buildings are rare, land is cheap, and less water is to be dealt with. If a new channel were to be constructed there now, or before the character of the district were much altered, an open channel would be cheaper. In making an estimate of cost we have, however, assumed that a covered one would be built. It certainly would be preferable, and by the time any new channel there is considered necessary, it probably would be cheaper.

In extending the proposed lower channel up to the Bussey-park brook at Forest Hills, its size and shape remains unchanged, the diminution in the quantity of water to be carried by it as it ascends the valley being offset by the slighter inclinations which are obtainable. Above the Bussey-park brook, for a distance of 3,250 feet, the channel is diminished in size to 14.5 feet high by 15.5 feet wide. At the confluence of the Roslindale branch the structure is again diminished to 13 feet high by 14 feet wide, which size is maintained for 3,100 feet to the Franklin-park branch. Above that point, for 3,250 feet, to the Hyde-Park line, the size is 8 feet 11 inches high by 9 feet 6 inches wide.

The following is the location of the proposed new upper channel, so far as we have thought necessary to select it: From the upper end of the proposed lower conduit the extension of it follows the line of the old channel as far as the outlet of the Pynchon-street culvert. Thence the line runs through private property, just west of the railroad location, to Heath street, into which it turns and reaches the upper end of the Pynchon-street culvert. The Pynchon-street culvert can be retained as an auxiliary channel, but, as it can only flow about half full without allowing the surface of the water to rise higher than the high-water line adopted, the quantity of water which it can convey safely will not be great, and will not much diminish the capacity needed for the proposed new conduit parallel to it.

From the upper end of the Pynchon-street culverts to

above Boylston street the line of new work must coincide very closely with that of the present channel. Above Boylston street it may be preferable, occasionally, to locate the new conduit in adjacent low lands, or in streets nearly parallel with the brook. The advisability of any such locations may be so affected by changes in condition, occurring before the new work is built, that we have not thought it expedient to indicate any definite location, but have based our estimate of cost on the assumption that the line of the new conduit will follow that of the present channel.

When the proposed new lower conduit is extended up the valley, water will no longer flow down the old channel to the Boston Belting Co. Compensation on this account will doubtless be claimed by the company.

Until the proposed lower conduit from above the Metropolitan car-stables in Roxbury to Back Bay shall be built, danger of flooding to Roxbury below Elmwood street will exist. There is no other way to do away with such flooding, due to severe freshets. The danger of flooding, due to minor freshets, may, however, be lessened by two precautions. One of these is to free the present channel, as far as possible, from all obstructions and accumulations which lessen its capacity for discharge, and to maintain it in that condition. Another is to avoid enlarging the street culverts above, by which more water can flow down upon the city.

SUMMARY.

Our recommendations may be summarized briefly, thus: —

1. To prevent floods in Roxbury, at and below the works of the Boston Belting Co., we recommend the construction of a new channel, of capacity for discharging 2,000 cubic feet of water per second, from a point 700 feet above the Tremont-street crossing of the Boston and Providence Railroad, to the pond of the Back-Bay park; a distance of 4,542 feet. We estimate the cost of this section of conduit to be $593,880.

2. Whenever it shall be decided to do away with the

danger of flooding in West Roxbury, we recommend that the lower section of conduit, just mentioned, be extended up to the junction of the Bussey-park brook, above Forest Hills station. This section is 13,650 feet long, and we estimate its cost (excluding land damages) to be $1,319,851. Above the point indicated, the new channel may be continued a further distance of 9,600 feet, to the Hyde-Park line, either as a covered conduit, at an estimated cost (excluding land damages) of $575,475, or as an open channel, as shall then prove most expedient and economical.

3. At some time in the distant future, should West Roxbury be solidly built up, and the conditions of the land surface become such that the rate of flow into the brook channel, in time of extreme freshet, may exceed its capacity; we recommend that a conduit, chiefly in tunnel, be built from the confluence of the main stream and the Franklin-park branch, by a line indicated on Plate I., to Neponset River. This we estimate will cost, at present prices, about $1,000,000.

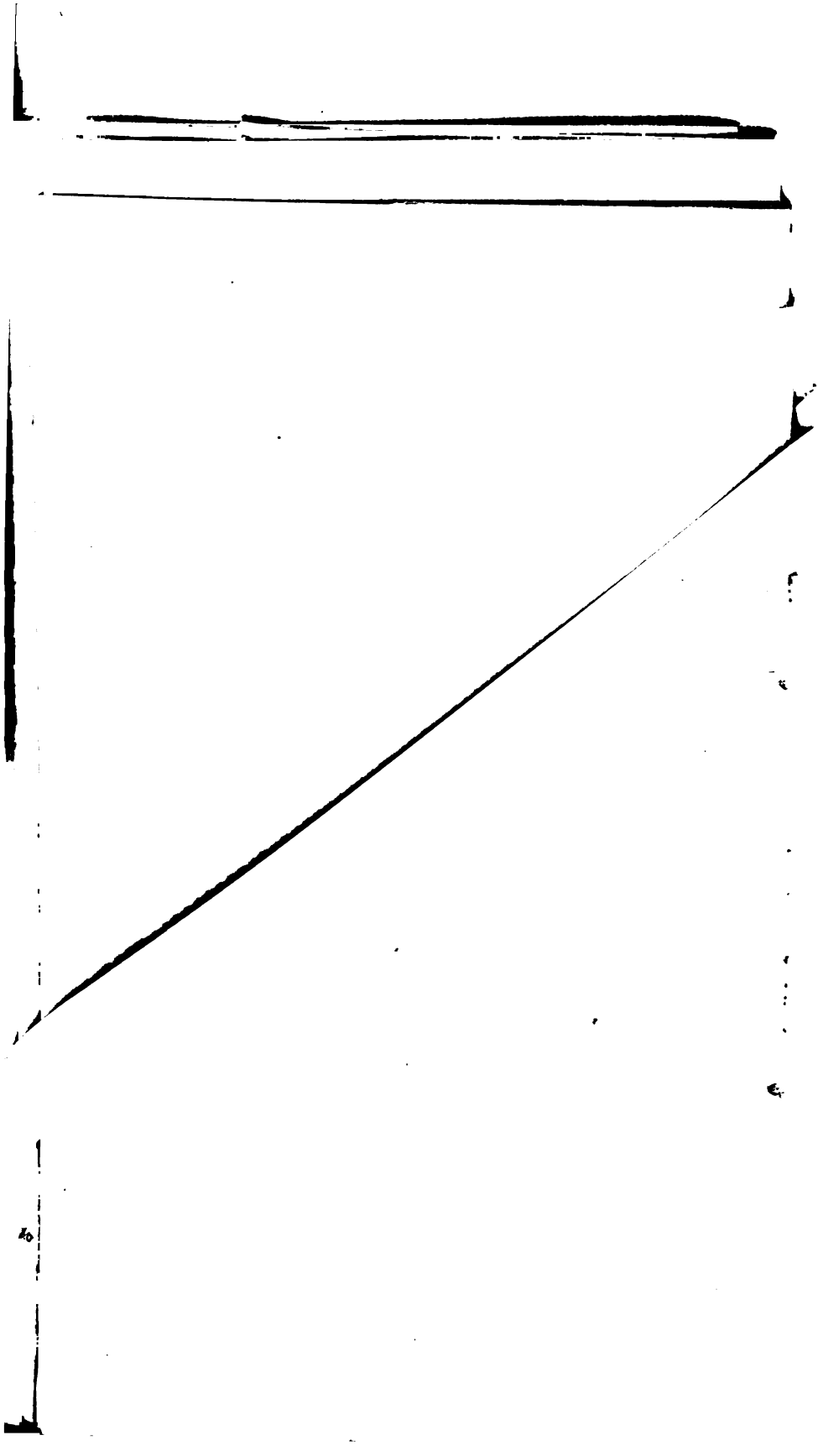
4. Until the lower section of conduit, first referred to, be completed, we recommend that no increase in size of the street-culverts over the brook, in West Roxbury, be made; also, that the present channels below the Belting Co.'s works be freed from all obstructions and accumulations, and be kept clean by continual care, and that from the upper channel everything be removed which might be brought down by freshets to clog the lower channel.

We desire to express our appreciation of the assistance we have received from the City Engineer's department, in making surveys and plans and collecting information, and especially to Mr. F. P. Stearns, of that department.

Respectfully submitted,

JAMES B. FRANCIS,
ELIOT C. CLARKE,
CLEMENS HERSCHEL.

BOSTON, MASS., July 27, 1886.



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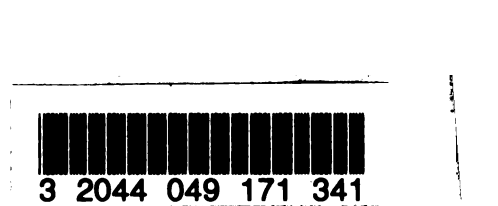
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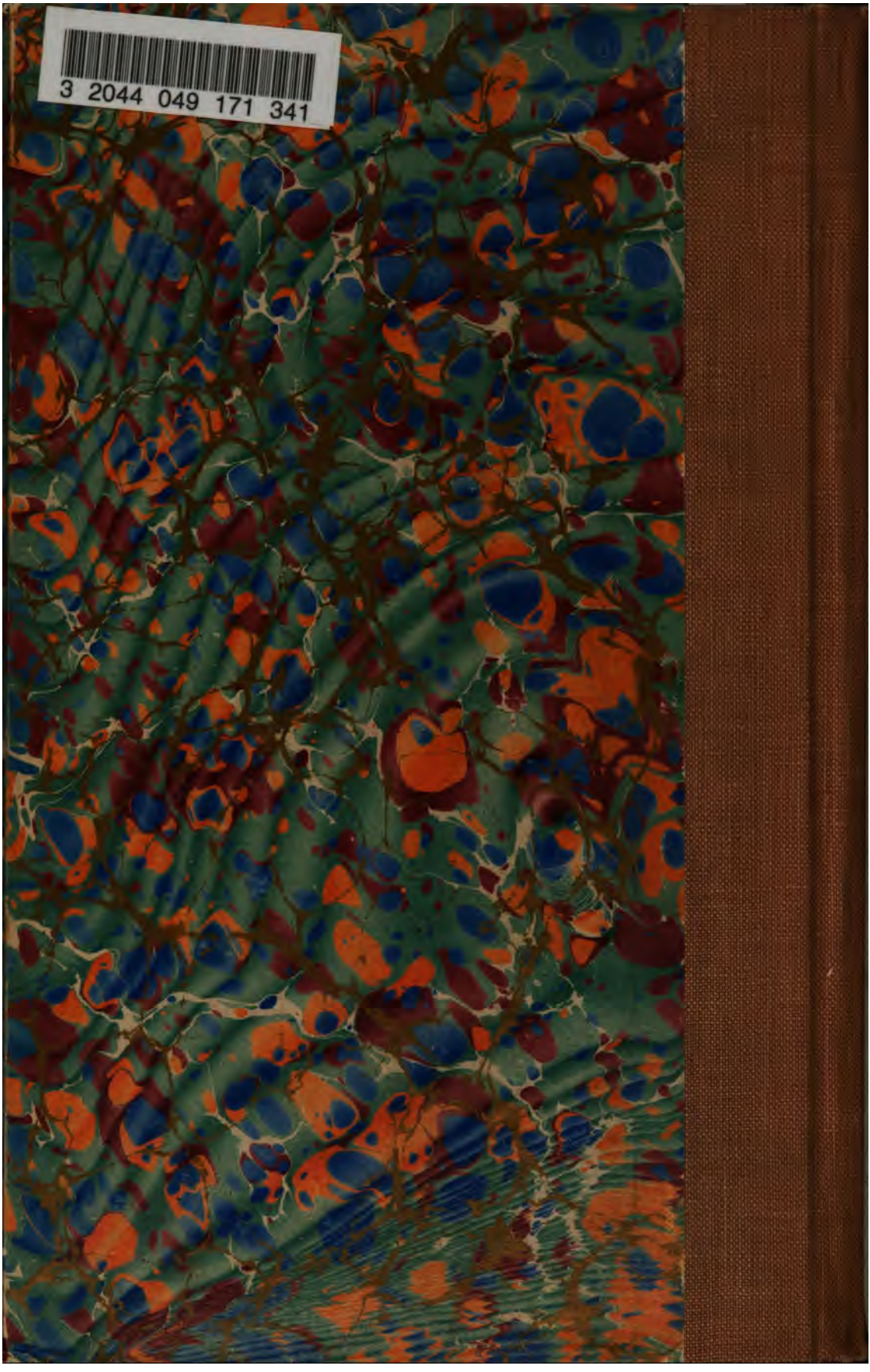
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